VERIFYING CURRENT CONDUCTION IN A LOW ENERGY PLASMA

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Abstract

A novel method of generating a low energy plasma utilizing the underlying characteristics of exploding wires was investigated. The plasma was formed by exciting the metallization on samples of polypropylene film with an impulse voltage of 2500 V. A concise method of simultaneously measuring the low energy plasma's current, light intensity, and event duration in the infrared spectrum was performed. The afore mentioned quantities were measured using three independent methods in order to achieve the best representation of the low energy plasma. A streak imaging system was designed, and utilized to capture the time duration of the plasma as a representative image on a digital camera. Pin photodiodes were used to measure the time duration of the infrared spectrum. Current was measured using an inductive probe. Time measurements taken from the photodiodes, streak imaging system, and current monitor all correlated to one another.

I. INTRODUCTION

Precise measurements of fast transient events have always been challenging. Usually, it is through a combination of methods that allows for a determination of an unknown quantity. Exploding wires fall into the category of a fast transient event. Under traditional experimental setups, exploding wires are a small wire of uniform diameter subjected to a very high voltage through a capacitive discharge. The current flowing through the wire is much more than it can handle, and the wire explodes, transitioning to a metal vapor plasma in the process [1-6].

This paper examines a different geometry of exploding wires by substituting a metallized polymer film as a surrogate exploding wire. The "wire" in this case is an aluminum metallization that has been evaporated/sputtered onto one of the surfaces of the polymer film. The thickness of the aluminum metallization is approximately 100 Å and the thickness of the polypropylene film substrate is 7 µm. This is shown schematically in Figure 1 where the additional dimensions are also shown. The geometry of the metallization was slightly altered to allow a precise plasma ignition, or flashover, in specific locations on the metallization that are referred to as "bottlenecks". These bottlenecks are visible in Figure 2. The bottleneck width was between 1 and 3 mm.

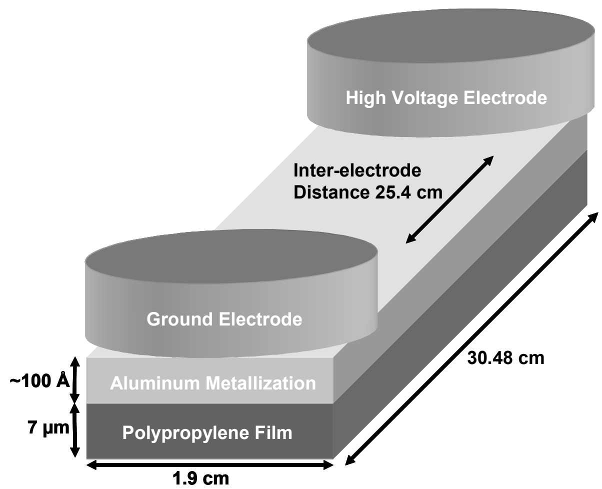

Figure 1. Representation of metallized polypropylene film under test (electrodes are stainless steel)

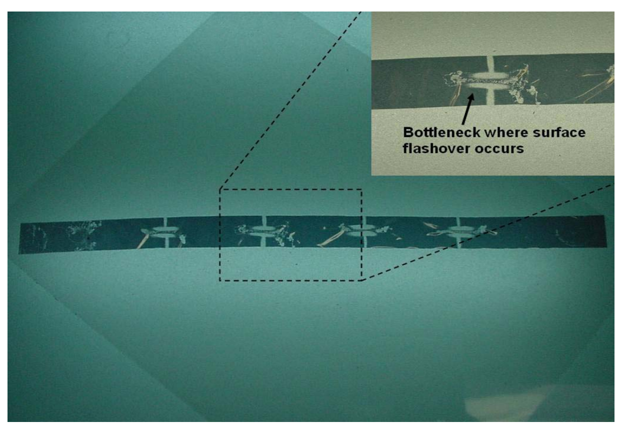

Figure 2. Top view of metallized polypropylene film with close up of bottleneck were precision flashover occurs

II. EXPERIMENTAL SETUP

To achieve a precise measurement of time duration of the metallization flashover, various methods were assessed. The initial experimental setup consisted of

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the film and electrode configuration (shown in Figure 1), and a capacitive discharge power source shown in Figure 3 was developed to carry out this study. The pulser contains a 2.6 µF capacitor in parallel with a 20 MΩ bleed resistor to safely discharge the capacitor. The output of the pulser was connected to two stainless steel electrodes as depicted in Figure 1. Each electrode was 2.54 cm in diameter with the spacing between the high voltage electrode and the ground electrode measuring 25.4 cm.

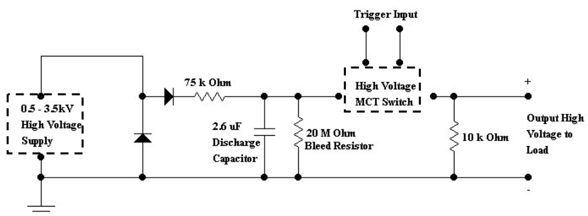

Figure 3. Schematic of capacitive discharge pulser

To perform the experiment, the capacitor was charged to 2500 V_{dc} for applications beyond the scope of this paper. The open circuit between the pulser and the metallized polypropylene film was closed via an NMOS controlled thyristor. Current measurements were taken with a small Pearson current transformer placed around the high voltage lead going to the film. Voltage measurements were accomplished by incorporating a Tektronix P6015 probe connected to the high voltage lead of the capacitor.

A. PN Junction Photodiode Measurements

In addition to current and voltage measurements, the time duration of the plasma flashover was measured via a PN junction photodiode array. A schematic of the array is shown in Figure 4. The photodiodes had a response time of 1 ns, and their peak spectral sensitivity wavelength is 800 nm (near the infrared spectrum). This particular wavelength was chosen because near infrared photodiodes offered the fastest risetime, which is important when capturing transient events.

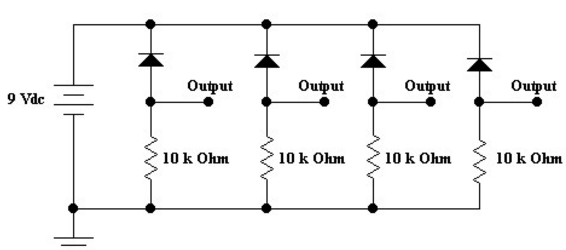

Figure 4. Schematic of PN junction photodiode array for measuring time duration of the metallization plasma

Each of the photodiodes were placed directly over the bottlenecks in the metallization of the polypropylene film. When the metallization flashed, the photodiodes relayed the signal to the Tektronix digital oscilloscope where the time duration was recorded.

B. Streak Imaging System

The third method in measuring the time duration of flash of the metallization plasma incorporated a streak imaging system. The rotating mirror assembly was controlled via pc and microcontroller. A generalized flow diagram of the setup is shown in Figure 5.

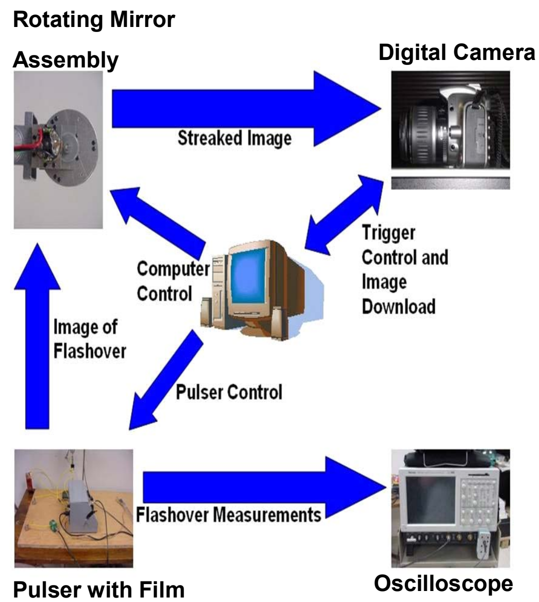

Figure 5. Flow diagram of streak imaging system.

The mirrors were calibrated to precisely streak the images of the bottleneck flashes across the open shutter of the digital camera. The mirrors rotated such that the beginning of the flashover was reflected to one side of the open shutter. As the mirror continued to rotate, the image got streaked across the open shutter until it reached the opposite side from which it started. If the flashover was not completed, the next mirror started the process over again, except this time starting with the tail end of the flashover instead of the beginning. If this happened, then a double exposure would have taken place with the second flashover superimposed over the first flashover. The mirrors were not in perfect alignment, so a phase shift in the image would be visible.

Trial and error was used to coordinate how fast the mirrors should be spinning, and when to trigger the flashover so that a useful image could be captured. To determine the time duration of a useful image, a test was done with four blue LED's. These LED's were aligned in a row so that their image could be streaked across the open shutter of the camera. One at a time, each led was turned on for 25 µs and then turned off. As soon as the previous led was turned off, the next led

was turned on for another 25 μs, and then turned off. This process was repeated for each of the four LED's. The digital image showed a set of four even lines, each staggered so that they looked like a staircase. The length of these blues lines could be measured in pixels to give a relation between the number of pixels showing on a streaked image to its actual time duration. Figure 6 shows the streaked image of the LED's. By using this method, the time duration of the streaked images of the flashovers at the bottlenecks could be compared with the photodiode, voltage and current data.

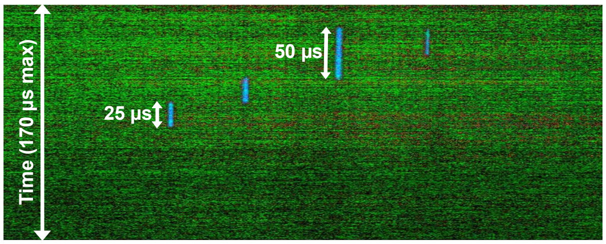

Figure 6. Enhanced streak image of the LED's to calibrate streak imaging system

III. RESULTS OF MEASUREMENTS

Comparisons of results between three different measurement methods yielded similar results. It should be noted first that measurements with PN junction photodiodes were not taken at the same time as the streak images. The placement of the photodiode array would have blocked the flash from the aluminum plasma from reaching the open shutter of the digital camera.

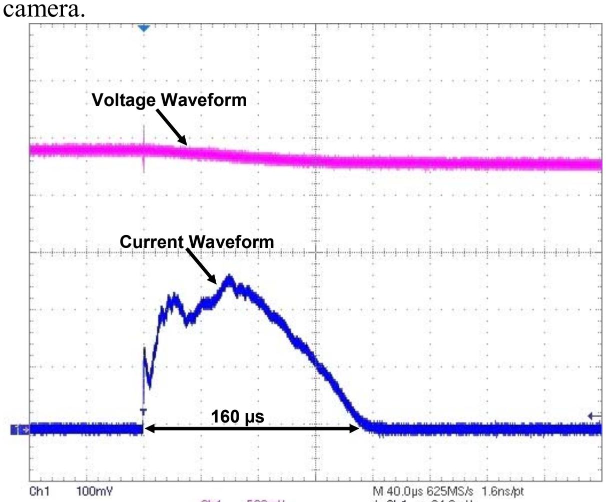

Figure 7. Voltage and current waveform of aluminum metallization plasma flash.

Figures 7 and 8 show the time duration of the flash as recorded by the current monitor and the streak imaging system. In Figure 7, the current is represented by the lower of the two waveforms. In Figure 8, the streaks from each of the bottlenecks are shown. Each of the bottlenecks are labeled "2" at the bottom of each one. The streak of "1" is where arcing from the high voltage electrode to the metallization occurred. Figure 9 shows the duration of two of the photodiodes as well as the current and voltage waveforms for one of the experiments.

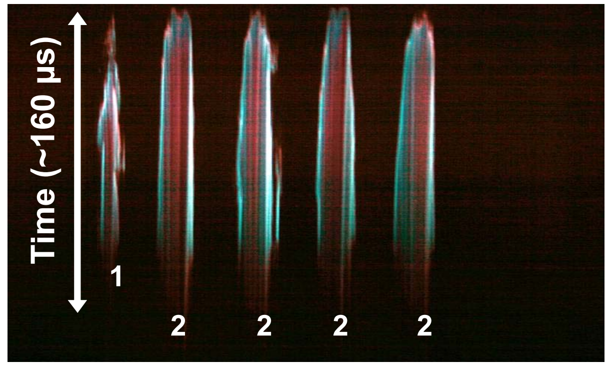

Figure 8. Enhanced streak image of four bottlenecks during aluminum metallization flash

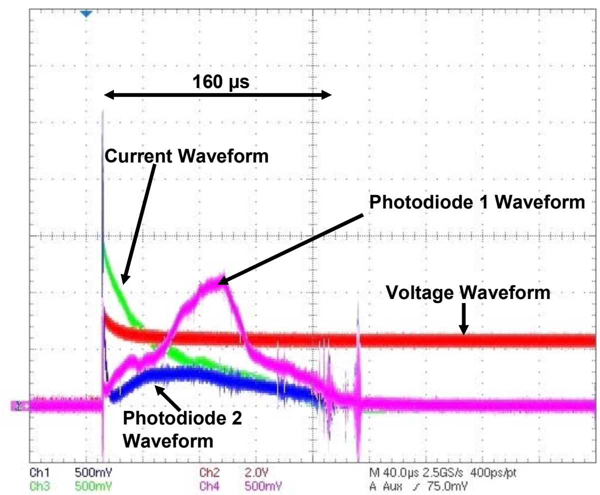

Figure 9. Photodiode waveform superimposed with current showing similar measurements of time duration.

Note that when taking voltage and current readings simultaneously with photodiode measurements, two channels on the digital storage oscilloscope were unable to be dedicated to two of the photodiodes in the array due to the fact that the oscilloscope only had four channels with two of the channels being dedicated to the voltage probe and current monitor. The photodiodes on opposites ends of the array were used to try to capture the velocity of propagation of the metallization flash across the polypropylene. By comparing the difference in time between the photodiode closest to the high voltage electrode and the photodiode closest to the ground electrode, a determination of the velocity should have been determinable. Upon analysis of the waveforms, no noticeable lag was observed indicating a propagation time of less than 1 ns. When comparing the

photodiode measurements with the current, and streaked images, it shows that all measurements converge at about 160 μs.

V. Conclusions

An approach to correlate three different methods of measurement for a fast transient event was developed with experiments performed. Each of the three methods, current monitor, PN junction photodiodes, and streak imaging system, all converged to the same time of the measurement of an aluminum metallization plasma discharge. With these tools proven to be in agreement with one another, various parameters of transient events can be capture with increased certainty of their duration in time.

VI. Acknowledgements

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